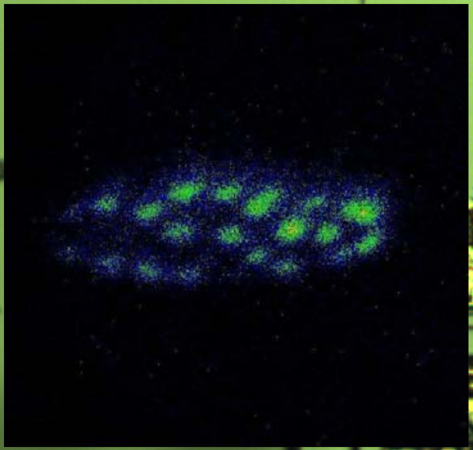
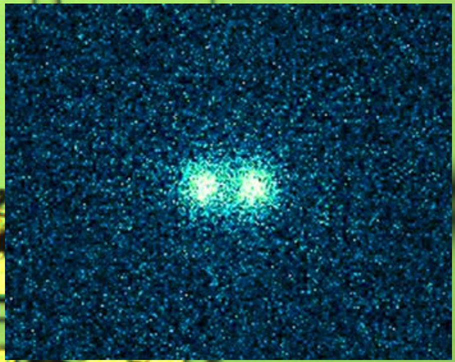
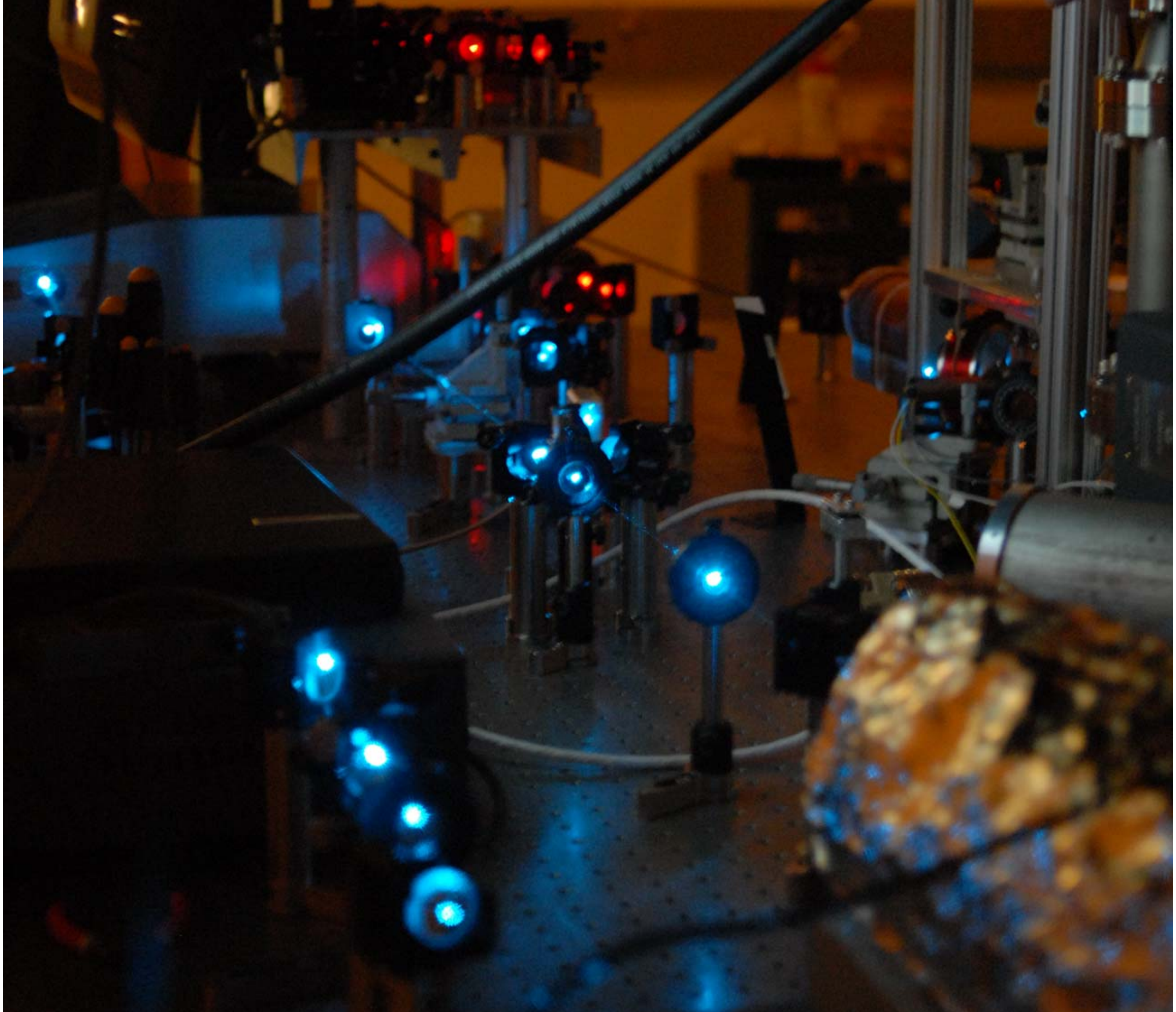
Quantum Computing with Individual Atoms and Photons







Today's Physics Colloquium:

Prof. Larry Dalton (University of Washington Chemistry)

Understanding intermolecular interactions in condensed matter: Effects on order and nonlinear optical properties

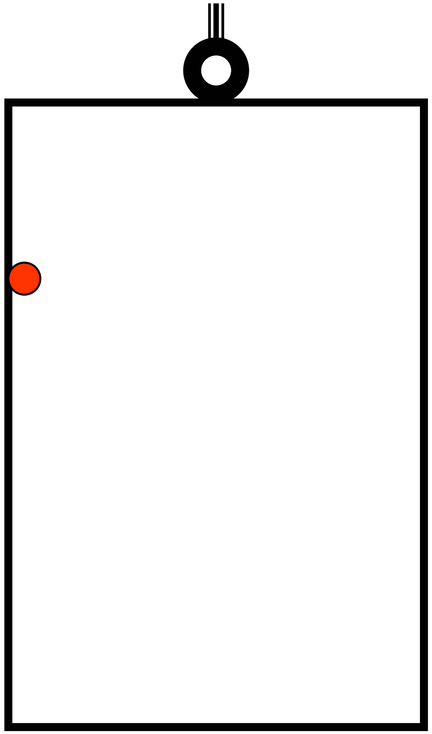
Physics 311
Special Relativity

Lecture 3:
Latticework of clocks.
Rocket frame

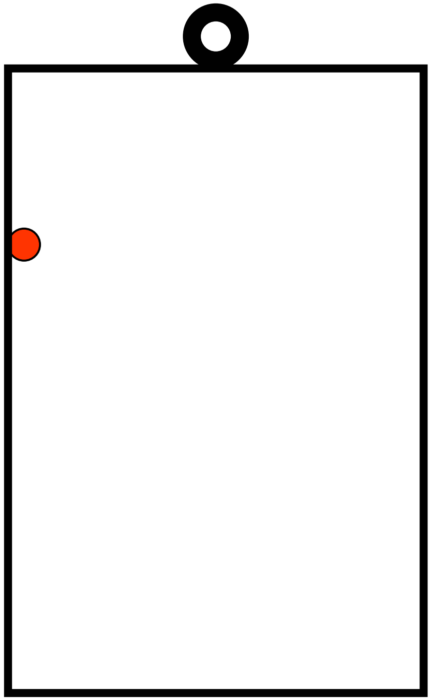
OUTLINE

- Defining the *local* inertial frame of reference
- The Observer
- Synchronization of clocks
- Moving frames

Newtonian vs. Einsteinian inertial frame



elevator at rest w.r.t. Earth

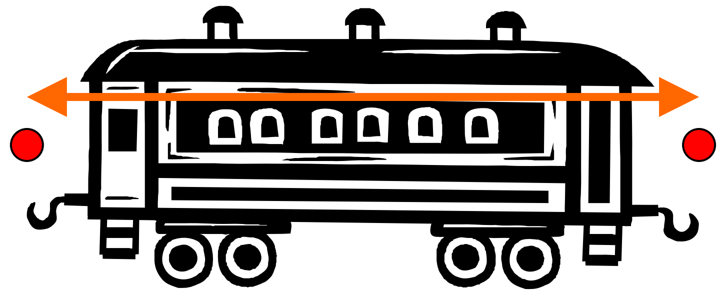


- Newton: gravity is a force; thus a frame at rest w.r.t. Earth is inertial
- Einstein: gravitation is the property of spacetime near massive objects; thus only a free-fall frame is inertial

elevator in a free-fall (free-float)

Regions in spacetime

- Recall the railway coach: 20 meters long
- In freefall, two test particles moved about 1 mm relative to one another in 8 seconds (which is about 2.4×10^9 meters of time)



d = 20m

d = (20 – 0.001) m

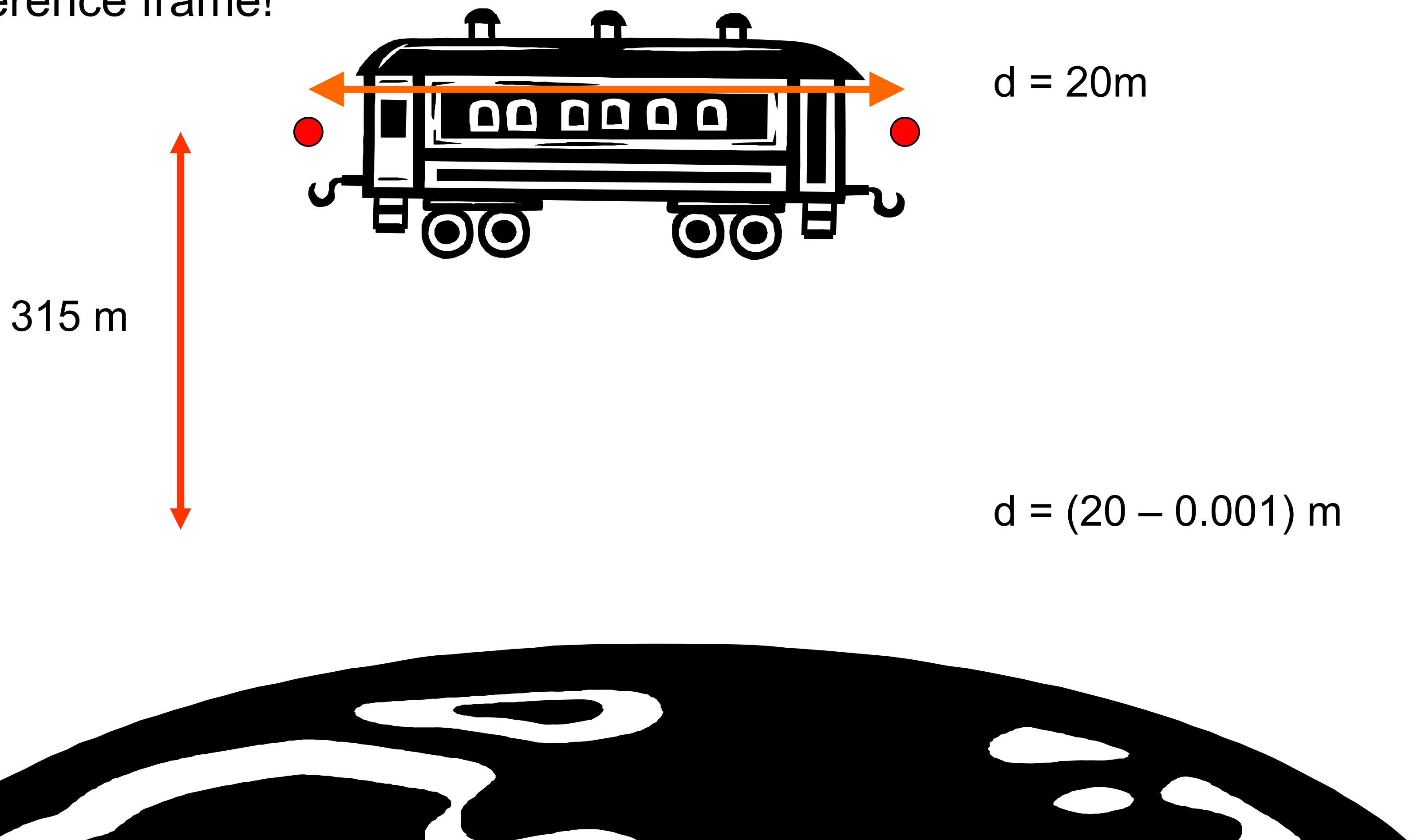
Regions in spacetime

- Recall the railway coach: 20 meters long
- In freefall, two test particles moved about 1 mm in 8 seconds
  (which is about 2.4 x 10^9 meters of time)
- Assume that 1 mm is less than the minimum detectable distance
- Then we can take a cube of space 20 x 20 x 20 m^3 and a lapse of time of 8 s = 2,400,000,000 m such that within that spacetime the test particles will not detectably deviate from their paths.
- We've got a ***local*** inertial reference frame! It's a region in spacetime with dimensions:

(20 m x 20 m x 20 m of space) x 2,400,000,000 m of time

But why 20 m x 20 m x 20 m? The car moved ~ 315 meters vertically in the 8 seconds – why not say 20 m x 20 m x **315 m** of space?

The answer is simple: the distance (315 meters) is measured with respect to Earth; the car moved quite differently w.r.t. Sun, or the center of the Galaxy. This motion is *irrelevant* to the size of the reference frame!



Here’s a problem:

- Say, we want to describe the motion of something BIG. Example from the textbook: a comet head. As something big like that travels through space, the gravity of the Sun (mainly, unless the comet plunges into Jupiter) causes tidal forces. The relative motion (acceleration) of particles surrounding the comet cannot be neglected.

- One solution is to break the space around the comet into sufficiently small regions; each of these will be an inertial frame. The motion of the parts of the comet can be described in these smaller frames.

- But: only General Relativity can answer the question of the motion of the comet as a whole.

Test particle

- How small is a "test particle"?
- Using Newtonian mechanics terms, gravitation of such particle must be negligible (within the specified accuracy)
- OK, but what about shape, size, mass of the test particles? Does it matter?..

... no! Acceleration produced by gravity is the same regardless of the mass, shape, color or smell

- But you may want to talk to the gravity research folks here at UW, they know a lot more about this. They may even know something that's not in the textbooks! (Yet)

Latticework of clocks

- Recall: ***event*** is the fundamental concept in physics in general, and definitely in this course. Event is defined by its position in space *and* time.

- Measure space with meter sticks. Measure time with clocks.

- Alright, the meter stick is there *all the time*. We can use it to measure the event's position at any time coordinate.

- What about the clock? Is it *everywhere* in space? NO! The clock is here, it is *local*.

- To make a good reference frame, we need to fill the space with lots and lots of clocks.

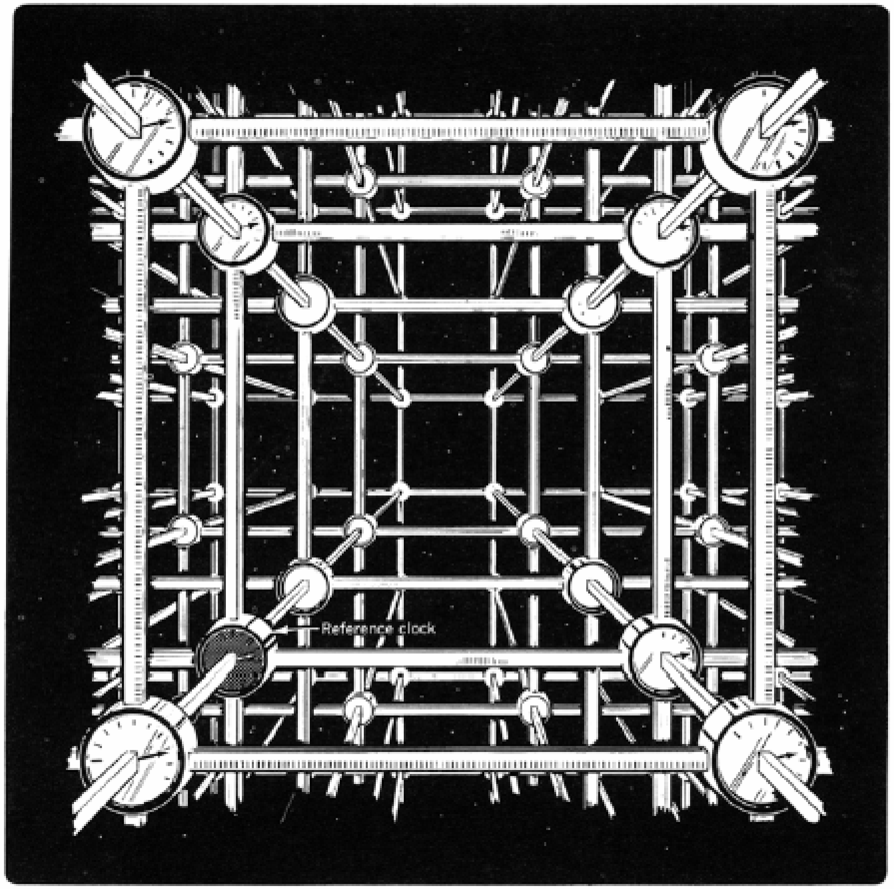


***Figure 5** Latticework of metersticks and clocks*

Synchronization of clocks

- All these clocks must show the *same* time. What do we mean by the "same time"? We mean that the clocks are *synchronized*.
- The recipe for clock synchronization:

  1. Pick the *reference clock*.

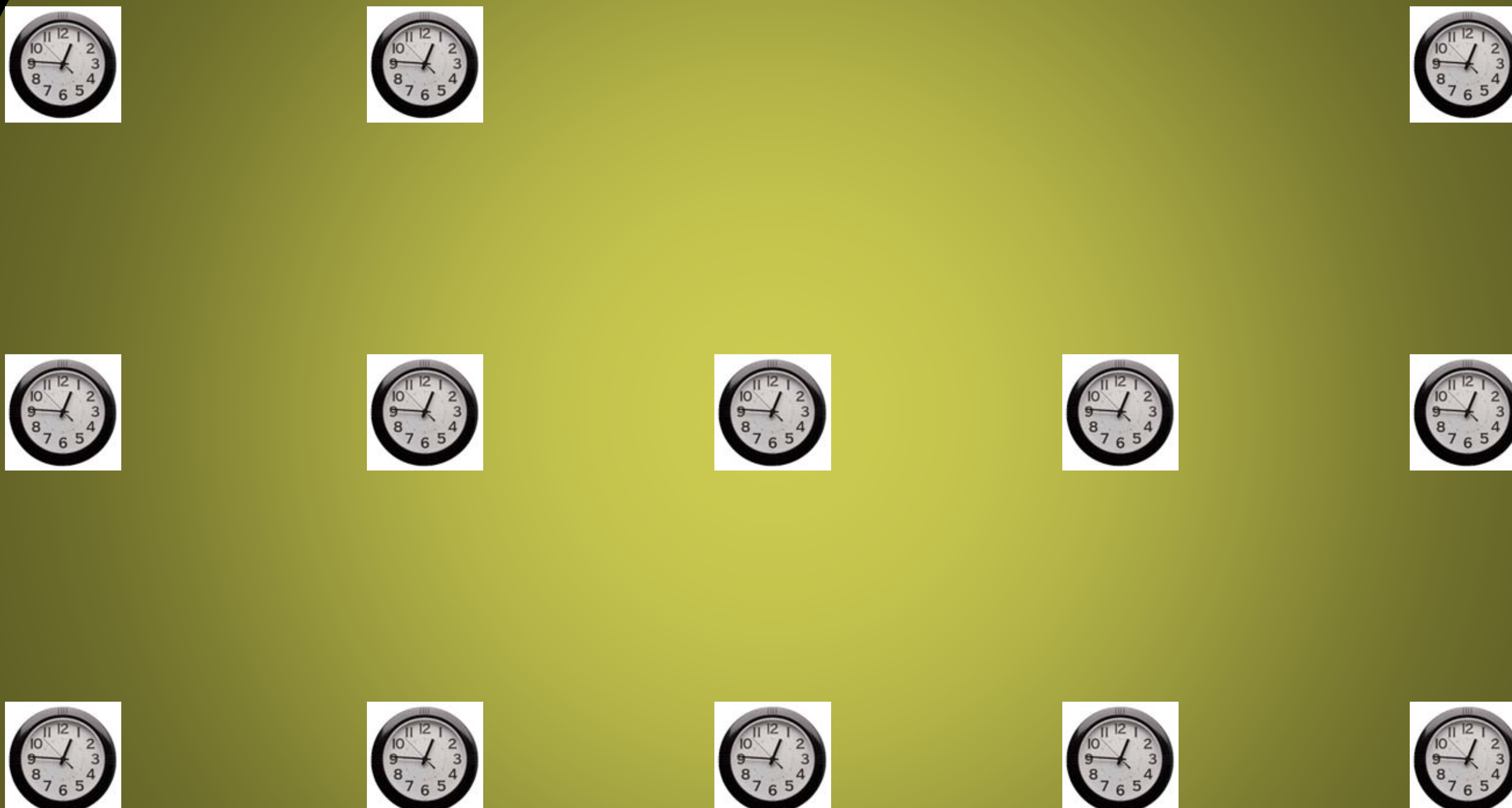
  2. Start the reference clock at 0 meters (of time!)

  3. Send a signal (radio, optical, microwave, x-ray, γ-ray, death-ray) from the reference clock at that instant, that will spread in all directions

  4. When the signal reaches the clock X located x meters away, set the clock X to x meters (of time).

  5. Do so for all clocks. Your clocks are now synchronized.

Synchronization of clocks



Do you see a problem with this picture? Maybe?

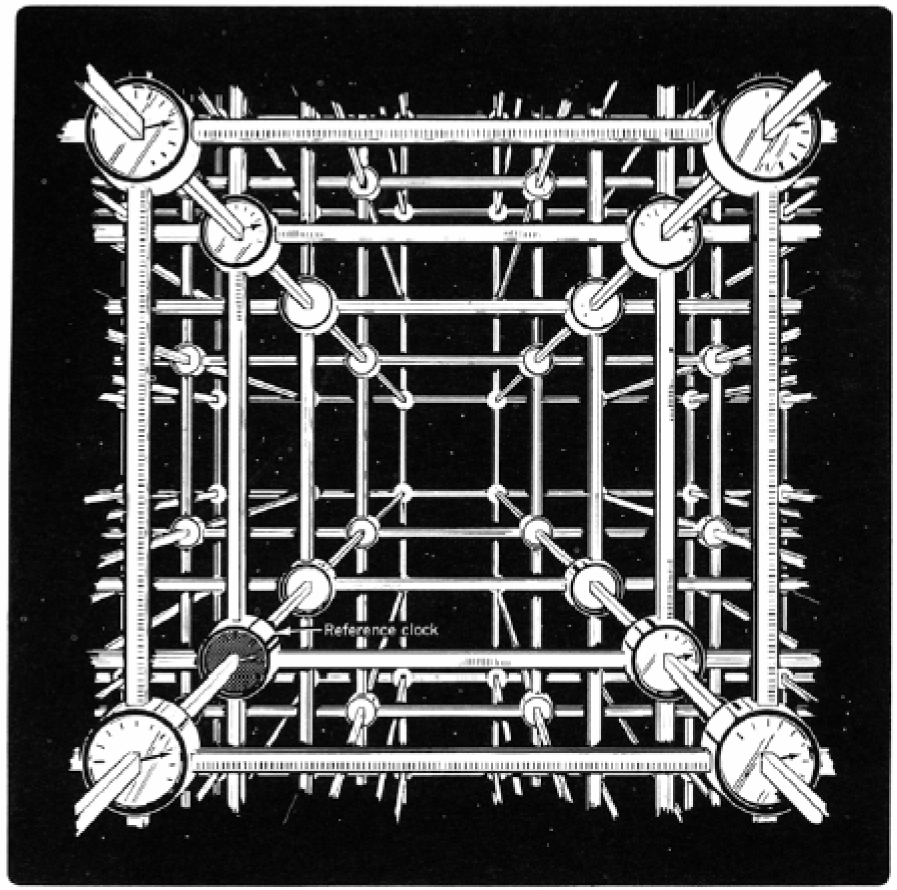


Figure 5 Latticework of metersticks and clocks

How many clocks? (How dense?)

- Depends on what you're measuring! (What ARE we measuring by the way?..)

THINK....

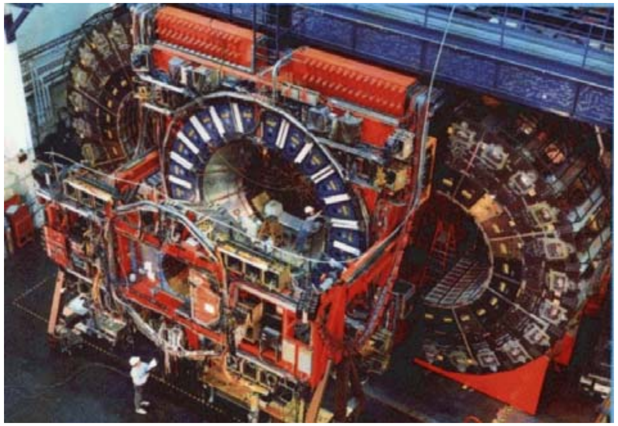
Think...

think...

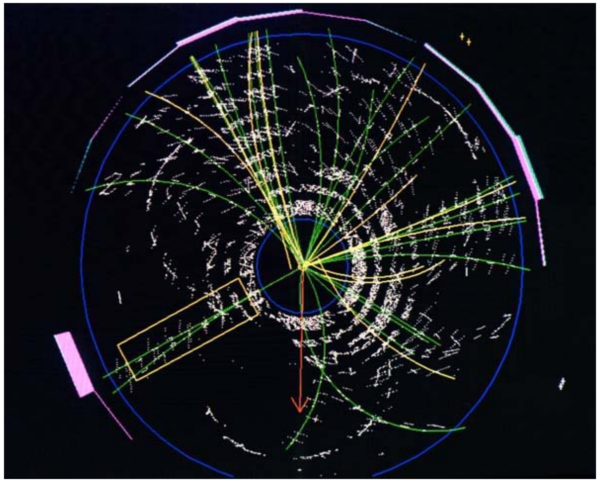
- That's right, we are measuring events!
- Each event is recorded by the clock nearest *in space* to that event. The clock's location on the lattice determines the event's spatial location; the clock's time reading determines the time coordinate of the event.

So... How many clocks?

- Particle detectors: every millimeter, or maybe centimeter. Particle detectors really truly record events!



CDF detector at Fermilab



Events at the CDF detector

- Ultrarelativistic spaceship detectors: every kilometer may be too close!

Observer defined

- The "observer" in relativity is all over the place. Well, all over their inertial frame, anyway. The latticework of clocks associated with the reference frame ***is*** the observer.

- The observer is nearsighted. We do not allow our observer to look at the events far away. The events are recorded by the *nearest clock*.

- The observer collects the data from the clocks and catalogues all events. If the size of the inertial frame is big, it may take a good long while to collect all the data. Example: the Hubble Space Telescope is collecting data on events that happened 13 billion years ago!

Moving frames. Finally!

- Moving – at what speed?

speed = (distance [m])/(time [m])

= (speed [m/s])/(speed of light [m/s])

- We use speed of light as the unit of speed. Common notation in literature for speed in these units: $\beta = v/c$, but we'll just use *v* or *u*.

- Consider two frames, in motion with respect to each other. We are sitting in one of the frames. We call that the **Lab Frame**. We insist that the other frame moves with ***constant*** velocity with respect to our frame. Then, if our frame is an inertial frame, the other one is also inertial. (Just think about it for a moment: "motion of the test particles remains unchanged...")

- We call the moving frame the **Rocket Frame**.

Different frames – different results

- Problem: the Lab observer (sitting really still) sneezes (Event 1); 5 seconds later she sneezes again (Event 2). (Is it the flu season yet? or just the Lab Dust?). The Rocket observer is flying by at v=Mach 3. What is the space separation between the events in the two frames?
- Naïvely: 0 meters in the lab, Mach 3 x 5 seconds = 5104.35 meters in the Rocket

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- Naïvely: 0 meters in the lab, Mach 3 x 5 seconds = 5104.35 meters in the Rocket, but relativistically...

- Lab frame: $\Delta x_L = 0$ meters; interval $s^2 = (\Delta t_L)^2$ [m^2]

- Rocket frame: $\Delta t_R = \Delta x_R/v$

$$s^2 = (\Delta x_R/v)^2 - (\Delta x)^2$$

The interval is invariant. Substituting the numerical values gives us Δx_R = 5104.3500000295944264342677299896 (just a bit longer than (Mach 3) x 5 seconds)

Different frames – same spacetime

• While the Lab observer and the Rocket observer do not agree on the time and the space measurements, they do agree on the spacetime measurement – the invariant interval.

Regardless of how they (uniformly) move with respect to one another, they both measure *the same* spacetime.